SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, NOVEMBER 2, 1906.

CONTENTS.

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

THE CONCURRENCE AND INTERRELATION OF VOLCANIC AND SEISMIC PHENOMENA.[1]

THE noteworthy occurrences that have latterly so largely engaged the attention of vulcanologists and seismologists, and so deeply impressed the world with the sense of insecurity that attaches to life upon a still unstable planet, make perhaps pertinent at this time a re-inquiry into some of the general phases of the phenomena as they are thought to be known to us. In announcing certain conclusions in this paper which are at variance with the views held by seemingly the greater number of geologists, or at least the specialists in the fields of inquiry which the paper touches, the author recognizes that the facts or data bearing out his conclusions may be thought by some to be presumptive rather than positive; but, whether so or not, he believes they are of a kind that must be taken account of in whatever phase the inquiry is pursued, and that they are at least of equal value with those that are assumed to uphold the opposed or generally received conclusions.

The two most important contributions to our knowledge of volcanic and seismic

[1] Paper read before the Tenth International Geological Congress, held in the City of Mexico, September 6, 1906.

phenomena that have been made during many years, are, as I take it, to be found in the records of the disturbances that have for many years agitated Japan and in the cataclysmic events which in 1902 visited the Antillean and Gulf regions of America. These additions to knowledge may be briefly summarized as follows:

1. The recognition of the fact that in perhaps the most seismic portion of the earth's surface—and by application, not unlikely over the whole world—earthquake disturbances, especially those of greater magnitude, are almost invariably preceded, by from one to five or six days, by marked magnetic disturbances in the earth's superficial crust.

2. The close connection existing over vast areas of the earth's surface, as measured on the direct east-and-west line uniting Quetzaltenango, in Guatemala, with Martinique, between the earthquake and volcanic disturbances of a single or identical period of activity.

The relations of magnetic disturbances to earthquakes in the Japanese region would seem to be clearly indicated in the records of the earthquakes of Nagoya (Dec.–Jan., 1893–4), Shonai (Oct., 1894), the great seismic 'tsunanie' of June, 1896, Ugo and Rikuchis (1896), Rikuzen (1900), etc., which have been discussed in the reports of the Earthquake Investigation Committee of Japan. While it may be true, as this committee wisely reports, that 'careful examination and extensive comparison with magnetic observations abroad, as well as records of earthquakes and pulsatory oscillations,' will be required before any relations between the two phenomena can be considered as definitely established,[2] yet the facts are such as to leave little room for doubt in the premises. Indeed, we have the positive statement made by Yamasaki, in an address delivered before the geographical section of the University of Vienna, that every major earthquake that visited Japan during the ten years immediately preceding 1902, and most of the minor ones, were heralded in advance by magnetic disturbances. If such be the case, and there would appear at this time to be no good reasons for assuming that the facts are different from what they have been represented to be, then manifestly the *cause* of earthquakes (and here a special reference is made to those that are referred to as 'tectonic') must be sought for in conditions that have no immediate relation to rock displacements of the time of the earthquake itself—in conditions that may at this time be wholly beyond the field of investigation, and whose expression may be found in some special magnetic or electromagnetic quality of our planet. The remarkable magnetic disturbance which accompanied or followed the cataclysm of Pelée on May 8, 1902, and which in an interval of from less than a minute to two minutes was registered in nearly all the magnetic observatories of the world, from Maryland to Paris, Athens, Honolulu and Zika-wei, in China, may point to some significance in this connection.[3]

The logical deduction from the premise that has been stated must necessarily be, it seems to me, that, however pointedly a displacement along a line of faulting or elsewhere would seem to indicate the *cause* of an earthquake, such displacement must rather be looked upon as a *consequence* of the seismic jar. In other words, the slipping or torsion of a terrane did not make the earth-jar, but, on the contrary, it fol-

[2] Publications E. I. C., Tokyo, 1904, p. 81.

[3] The effect of strain within the earth's crust or mass as of itself initiating magnetic disturbance is not considered in this paper; but the subject has possibly an important place in this inquiry, and its elucidation may help to clear up some of the mystery that attaches to seismo-magnetism.

lowed in obedience to an impact already delivered, and naturally along lines of predetermined weakness. Indeed, there are many reasons for believing—but the facts can not be discussed in this place—that extensive slips along breakage-lines or lines of fracture, in any way correspondent to the long line of displacement which marked the late California earthquake, could not have been initiated without a precedent jar or impact; and still less could there be initiating displacement along a line of contact such (*e. g.*, between the looser materials of the coastal plain of the eastern United States and the compact sub-Appalachian border-rock) as had been advanced to explain the Carolina earthquake of 1886.

The extent of field which may be covered by interrelated volcanic and seismic disturbances of one period of activity, as is evidenced by the Antillean events of the year 1902, bears directly upon the question of the causation of certain earthquakes which have hitherto been thought to be of a purely tectonic character. The facts connected with the Antillean disturbances are briefly:

The destructive earthquake of Quetzaltenango, in Guatemala, on April 17–18, at almost precisely the time when Pelée first seriously manifested its new activity; the renewal of activity, immediately after the earthquake, and at a distance of nearly 200 miles, of Izalco, in Salvador, a volcano whose energies had calmed down for a number of years, but which was in full activity on May 10, two days after the Pelée cataclysm; the eruption on May 7, of the Soufrière, in St. Vincent; the cataclysm on May 8, of Pelée, followed, as in the case of the Soufrière, with violent disturbances extending into September or October; the eruption on October 24 (and continuing to Nov. 15) of Santa Maria, in Guatemala, a volcano situated close to the seismic field of Quetzaltenango, and for which there is no recorded previous eruption. The relation of these facts, it seems to me, is so conclusive that one need hardly discuss the probability of another interpretation being found for them; and it was not without reason, therefore, that Milne early advanced the view that the April earthquake of Quetzaltenango was the real initiator or instigator of the series of dual disturbances that followed rapidly upon it. The lid was taken off the boiling pot, and the pot exploded. Whether or not one should extend the relation of disturbances so as to include the earlier earthquake which in January of the same year wrecked a large part of the town of Chilpancingo, in southern Mexico, and the reawakening of Colima in February and March of the year following (1903), does not materially affect the problem, as the distance separating Martinique from Quetzaltenango is already so great as to fully satisfy the broad deduction which it is the aim of this paper to present. Owing, perhaps, to the fact that these disturbances were developed in what might be termed a single region, and in a region that is not familiar to us in the sense that parts of the world nearer to our homes are, the geologist is not apt to be impressed with the magnitude of the distance that separated them; it is, therefore, proper to state that on the map of the continent of North America it would be measured by the line uniting Galveston with Cape Churchill, on Hudson Bay, or that uniting San Francisco with the volcano of Iliamna, on Cook Inlet, Alaska.

Applying the test of distance in a possible relation touching the history of other (so-called 'independent') earthquakes, we find some not wholly uninteresting results. Thus, the great earthquake of Lisbon (1755), seemingly the most destructive of all the seismic disturbances which history

records, and which is ordinarily considered to be typical of the so-called tectonic earthquake (or earthquake independent of volcanic association), took place in a field which in a direct line is removed by 1,800 miles from the very active volcanic region of Iceland—therefore, at a shorter distance than Pelée is from Quetzaltenango. It is significant that a few days before the destruction of Lisbon the volcano of Kötlugia, in Iceland, broke out into violent eruption, and it is perhaps more than a coincidence that on the very day of Lisbon's fall (November 1) the activity of this volcano was particularly marked.[4]

It would perhaps be going in advance of the facts were we to immediately assume that the eruption of Kötlugia was directly related to the Lisbon earthquake; on the other hand, there would seem to be nothing to make this conclusion untenable. Indeed, this relation acquires a strong degree of confirmation from the events that a few years later (1783) marked the very disastrous earthquake of Calabria. At that time, although following the great shock (March 28) by several weeks, the volcano of Skaptar Jökull, in Iceland, went through its greatest paroxysm, discharging lava for a period of four months, and relieving the interior of the earth of a mass of rock-material which has been estimated to have been not less than 27 milliards of cubic meters—the equivalent of a block six and one fifth miles long, three and one tenth miles broad and 1,771 feet thick! The volcano of Reykjanes was likewise in eruption. These two volcanoes are located almost exactly 2,000 miles from the scene of the Calabrian disturbances, when the entire island of Sicily, in addition to the mainland of Italy, was affected. The same year witnessed also the explosion of Asamayama, in Japan, one of the most violent of all recorded eruptions, when rocks measuring 40 to 260 feet across are said to have been hurled out of the crater.[5] It should also be noted that this year marked the first recorded eruption of Irazú, in Costa Rica, which was accompanied by violent earthquakes.[6]

A partial and perhaps even very close parallel to the Antillean occurrences of 1902 may be found in the disturbances which framed the New Madrid earthquake in the valley of the Mississippi in (December) 1811 and 1812, that wrought the destruction of Carácas on March 12, 1812, and culminated in the great eruption of the Soufrière of St. Vincent on April 30, 1812. The association of events in these cases is such as hardly to permit of doubt in their reference. Indeed, it has been frequently stated (but I have not been able to find absolute confirmation of this assumed fact) that the movements in the Mississippi Valley ceased for a while, almost immediately with the breaking out of the Soufrière. A similar, although reversed, condition marked the earthquake of Riobamba, on February 4, 1797—perhaps the most destructive to life after that of Lisbon—when, as we are informed by Humboldt, the volcano of Pasto, situated 200 miles distant, almost immediately ceased smoking.[7]

The great earthquake which on February 20, 1835, destroyed the city of Concepción, in Chile, and which has been represented to be a distinctively tectonic quake[8] is almost certainly one of volcanic association, and so it has been referred by Milne, in his work on earthquakes (p. 135). The year 1835 was a particularly volcanic year in the Chilean Andes, and the reports of the

[4] 'Royal Society Report on Krakatoa Eruption,' p. 387.

[5] Milne, British Association Reports, 1887.

[6] Milne, 'Earthquakes,' p. 273.

[7] 'Views of Nature,' Bohn edition, p. 175.

[8] Dutton, 'Earthquakes,' p. 52.

officers of the *Beagle,* which happened to be at Concepción at the time of the earthquake, make clear reference to volcanic outbursts, one behind the island of Quiriguina and the other in the bay of San Vincente.[9] In the Royal Society Report on the Krakatao eruption we find the statement that all the Chilean volcanoes were active on the fatal February 20—a statement that in its broad reference, I believe, still requires verification. This earthquake was followed within a period of less than a month (March 15) by the great earthquake of Santa Marta, in Colombia and was preceded in the same period by the cataclysm of Coseguina, in Nicaragua (January 20, 1835), probably the most violent of all the paroxysms that had been reported up to its time from the American volcanoes.

The difficulty of distinguishing between so-called tectonic earthquakes and those having a volcanic reference has always been great, and it naturally increases the moment we fully recognize over what vast distances the interrelationship of the two classes of phenomena may be established. This condition was, indeed, long ago appreciated by Milne, who, in his work on 'Earthquakes' already referred to, very guardedly attempts to make the distinction upon which other seismologists, notably Montessus de Ballore, so positively insist. He accurately states the position, it seems to me, when he asserts that both phenomena may be merely 'different effects of a common cause' (p. 275) or as resulting from 'some great internal convulsion' (p. 270) —in which case 'an earthquake may be looked upon as an uncompleted effort to establish a volcano' (p. 275).

The few instances that have here been cited to show a very probable interrelationship between far-removed manifestations of volcanic and seismic disturbance may be considered insufficient to establish the relation which it is the aim of this paper to present, but it would not be difficult to largely multiply the cases of such apparent correspondence. They certainly suffice at this time to make very doubtful the commonly accepted limitation of the two main classes of earthquake disturbance, and show almost to a certainty that some, at least, of the most destructive earthquakes have been wrongly referred.[10] If it should be objected that a number, or even a very large number of the most far-reaching and, therefore, most typically 'tectonic' quakes, such as that of Arica, of August 13, 1868, or of Lima, of October 28, 1746, have seemingly not even a distant eruption on which to couple their history, it may be replied that many such quakes have been recognized to be of distinctively marine origin, and they could be easily related to a violent suboceanic eruption whose traces need in no way be made apparent at the surface. That such suboceanic eruptions do take place, no geologist denies, and it is further believed by many (as, for example, Rudolph) who have given the closest study to the nature of the great oceanic waves that have accompanied (or preceded or followed) some of the most violent seismic movements, that these waves have an absolutely volcanic origin—the waters being depressed or elevated as the result of volcanic and not of earthquake stress. It should also be noted in this place that a lack of synchronism in time by weeks or even months is not necessarily opposed to an assumption of interrelationship in action, since the *mani-*

[9] *Journ. Royal Geog. Soc.,* Vol. VI.

[10] As bearing further on this point it may be noted that the earthquake known as that of Valdivia, Chile, of 1822, whose effects were felt over a north and south extent probably considerably exceeding 2,000 miles, is classed by Dutton among the tectonic quakes, whereas by Milne it is placed among those having a volcanic association.

festation of action as it presents itself to us in time need by no means represent the *actual* time-period which marked the beginning or end of a disturbance, whether volcanic or seismic.

If we once assume, and as the facts seem to indicate justly, that an interrelation between volcanic and seismic disturbances may be extended over a region of 2,000 miles or more, naturally it becomes impossible to state to what further limits this relationship may not extend; in other words, how far removed may a volcano be from an earthquake to be brought into correspondence with it. This question can not now be answered, but it is certainly a significant fact that a very large number of the greater earthquakes have been at (or about) times when there have been violent or paroxysmal eruptions, however distantly removed the points of such eruption may have been. And it can also be stated that extreme volcanic activity in one part of the globe is frequently synchronized, or shortly followed, by similar activity elsewhere. This, in a measure, and perhaps equally so, holds true of earthquake disturbances. These conditions, taken in connection with the facts that have been earlier recited in this paper, it seems to me, tend to prove that a causal bond unites the two classes of phenomena, and that they have a common origin in some internal planetary stress or convulsion.

It has been claimed by those who sharply distinguish between volcanic and tectonic earthquakes that the earth movement, whether in force or in lateral extent, that distinguishes the former is small compared with that of the latter, but the facts that have already been brought forward render the accuracy of this conclusion extremely doubtful.[11] Indeed, the geologist, in the face of the far-reaching mechanical work of evisceration which so largely distinguishes many eruptions, would on *a priori* grounds be justified in hesitating before he announced this conclusion, and he could ask himself the much-neglected question: what must be the result of the removal in a short period of so much material from the earth's interior? The volcano of Askja, in Iceland, as a result of its eruption on January 4, 1875, is estimated to have thrown out from the rifts of the Mývatus Oræfi lava which in quantity measured 31,000,000,000 cubic feet, or the equivalent of a block 20 miles long, 5 miles wide and 100 feet thick.[12] The discharge from Skaptar Jökull, in 1783, was calculated, as we have already seen, to have equaled a block 6.2 miles long, 3.1 miles broad and 1,771 feet thick; that from Bandai-San, Japan, in 1888, 1.2 cubic kilometers; from Krakatao, in 1883, 4.3 cubic miles (!); and from Temboro, on Sumbawa, in 1815 (as estimated by Verbeck), 28.6 cubic miles. The geologist is in the habit of looking complacently upon the removal of this vast material from the earth's interior, but is it at all likely to have been accomplished without prodigious jarring of the earth's crust somewhere? It is only when we begin to properly appreciate the vastness of this evisceration that we are prepared to receive, apart from other evidence, the probability of far-reaching action in the eruption of a volcano. Even the minor quantity of material

[11] The breaking into activity of Klutchevskaya, the lofty volcano of Kamtchatka, on October 6, 1737, seems to have been the occasion of an earthquake which agitated nearly the whole of the Kamtchatkan peninsula and a large part of the region of the Kuril Islands. The earthquake which in 1861 annihilated the town of Mendoza, in Argentina, costing the lives of probably not less than 10,000 inhabitants, was coincident with the opening of the volcano of Mendoza near by; the earthquake of Arequipa, Peru, in 1868, was coincident with the opening of one side of the volcano of Arequipa (Misti).

[12] W. G. Locke, 'Askja,' 1881, p. 26.

thrown out by Skaptar Jökull would equal in quantity that which could be heaped up to a thickness of some seven or eight feet over almost the entire area which in California lies between the line of displacement in the recent earthquake and the Pacific Ocean; while the discharge from Temboro, if properly estimated, would have filled in a mile-wide canal to a depth of ten feet over a length of 15,000 miles. One may well stand appalled by these figures, but they have as yet produced little impression upon the geologist to whom the major lesson of vulcanology is taught by Vesuvius or Etna.

The general conclusions arrived at in this paper are:

1. A broad interrelationship exists between volcanic and seismic phenomena generally;

2. Interrelated manifestations of volcanic and seismic activity may extend over distances, as measured on the surface of the globe, of hundreds or even thousands of miles;

3. 'Tectonic' earthquakes, so-called, are only doubtfully to be distinguished from earthquakes of volcanic association, or those that have been brought about as the result of deep-seated strain;

4. The slipping, upheaval and torsion of terranes as accompaniments of earthquake action are the resultants of impacts or jars already delivered to the earth's crust, and are not the cause of such jars;

5. Earthquake and volcanic disturbances seem to be the expression of one common interior telluric strain or condition, and this condition may in some or many cases be clearly associated with a pronounced magnetic or electro-magnetic quality of the planet;

6. There would appear to be a marked synchronism or close following of major disturbances, whether volcanic or seismic, at distantly removed points of the earth's surface at certain periods.

ANGELO HEILPRIN.

SCIENTIFIC BOOKS.

The Adjustment of Observations by the Method of Least Squares with Applications to Geodetic Work. By THOMAS WALLACE WRIGHT, M.A., C.E., professor emeritus, Union College, formerly assistant engineer, Survey of the Northern and Northwestern Lakes. With the cooperation of JOHN FILLMORE HAYFORD, C.E., Chief of the Computing Division and Inspector of Geodetic Work, U. S. Coast and Geodetic Survey. Second edition. Pp. ix + 298. New York, D. Van Nostrand Company. 1906.

The average man of science generally exhibits a remarkable lack of ordinary common sense when dealing with the method of least squares and its conclusions. Inferences are drawn from a series of observations, and deductions made from the size of the probable error which at times seem so totally at variance with the truth that much fault has been found with the method. In theory, the probable error is based on the assumption that the errors are all accidental, that is, are just as likely to be positive as negative, and that there are a large number of observations, whereas in practise, the formula for finding the probable error is often applied to a very few observations not freed from their systematic or constant errors. A consequence of this is that a degree of precision is shown which is much greater than the observations themselves really warrant, and the probable error, therefore, does not seem an accurate measure of the error committed.

There are other scientists who believe that a least square reduction is a great correction of evils, and that by its means very satisfactory results may be derived from an indifferent set of observations. While poor observing will give nothing but poor conclusions, it seems to be quite a favorite trick of the computer, nevertheless, to introduce new unknowns into the observation equations with the hope of more correctly solving them. When